Robots in the automobile industry

multifunctional manipulators for tedious work

By Bernhard Krieg

Most robots in the world are used in manufacturing operations: assembly and inspection, processing, and materials handling. Their use in assembly and inspection is accelerating in line with the increasing cost of manual labour. Robots are the culmination of the automated production line. The first industrial robot was installed (and its programmable manipulator patented) about 40 years ago in the USA. Basically, a robot is controlled by a computer and carries out the received instructions by teleoperators (mechanical manipulators).

For as long as man has had to work, he has sought to unload some of the burden of labour to mechanical devices. It was not until the Industrial Revolution, however, that large-scale mechanization could take place. Once division of labour, that is the restriction of the activity of each labourer to one specific, repetitive task, had been adopted, it was a relatively simple step to develop machines (first steam, and later electric) to carry out these tasks.

Another step toward automation was taken with the introduction of assembly lines, which used a conveyor belt to move a job in stages from one worker to another.

Automatic transfer systems, developed during the Second World War, combined assembly lines with mechanization. However, true automation could not come about until the development of feedback systems. Such systems enable machines to monitor their own output, compare it with a set of standards, and adjust their operation accordingly if and when necessary.

A robot is such a machine to replace human effort. Some idea as to the effectiveness of robots may be gathered from the fact that in a modern car factory, such as the Daimler-Chrysler plant in Rastatt, Germany, 5000 workers and 380 industrial robots produce some 200,000 private cars per year.

Twenty-two hours

In the Daimler-Chrysler plant, it takes 22 hours for a complete car to roll off the production line. What part of the work is carried out by robots?

Clearly, before final assembly can be started, materials and other parts have to be moved from one location to another. Most of this involves robots picking up these parts from one conveyor and placing them on another.

In the assembly hall, robots fasten the panels to the chassis – up to the doors, but no interior work is done as yet. There are 290 different body parts and these are spot-welded together at 4000 different locations (**Figure 1**). The assembly hall is spacious enough to allow the 'herringbone' type of production line. In this, small subsidiary transfer lines (conveyor belts with ancillary production stations) are positioned at an angle to the main belt. This method of working ensures that the car body shell moves along the main production line at a fairly constant speed.

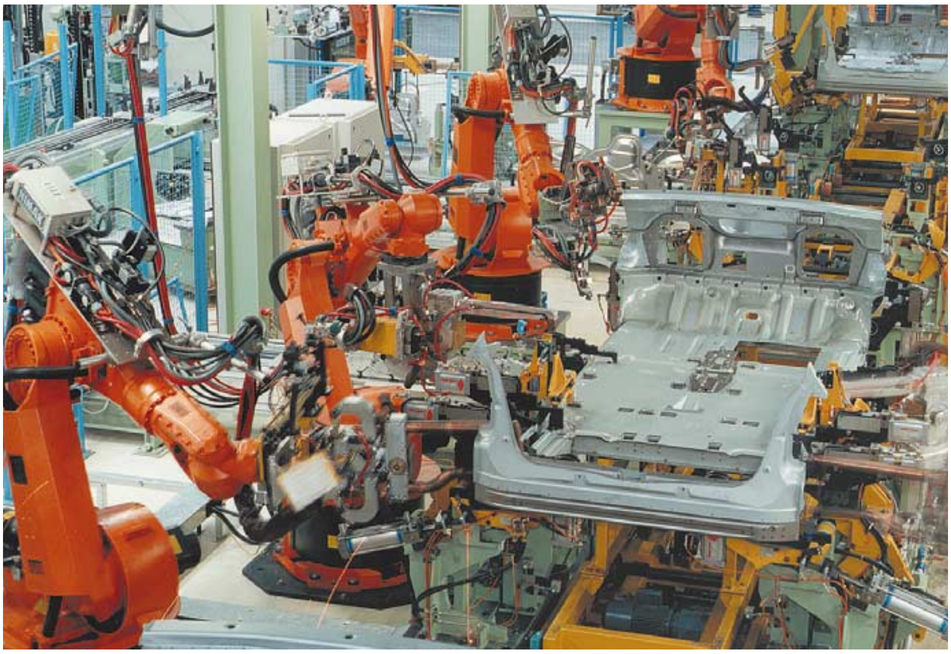
Figure 1. In the production hall 330 robots manufacture the chassis from 290 different parts. Shown is the completion of the understructure of the body.

Surface finishing

Robots are also used to paint the completed shell: naturally under clean-room conditions. Because of environmental considerations, only water-based lacquers – without a nickel or nitrate pre-treatment – are used. The lacquers applied by a dip and rotate process contain no lead. The final three films of paint are applied electrostatically to reduce overspray. Drying between the applications of the various layers is not necessary.

Since the first (body-colour) film also provides protection against stones thrown up from the road and colour change through ultra-violet light, the usual plastic (protective) film is

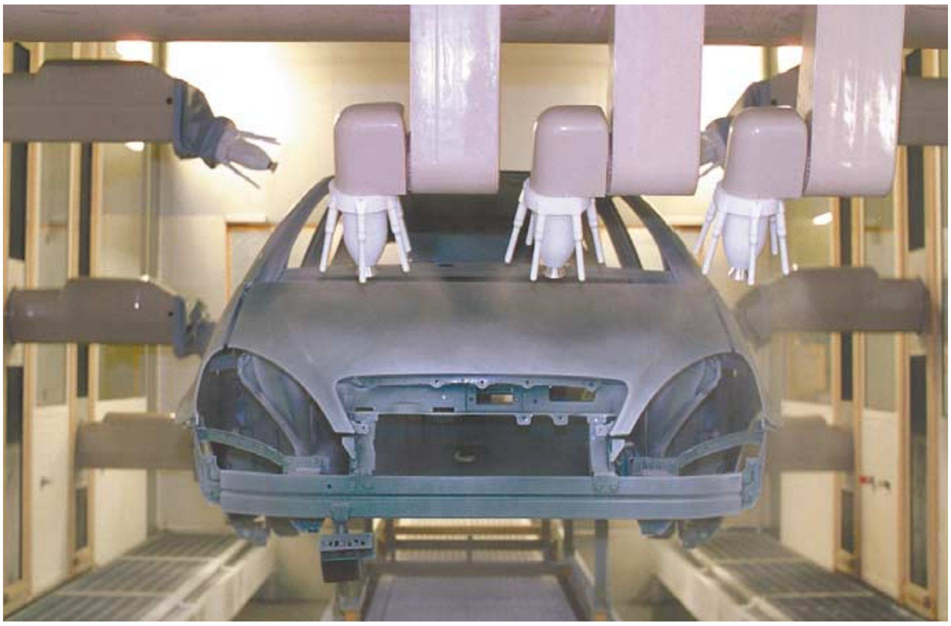
Figure 2. Application of the final (clear) solvent-free lacquer by a paint robot.

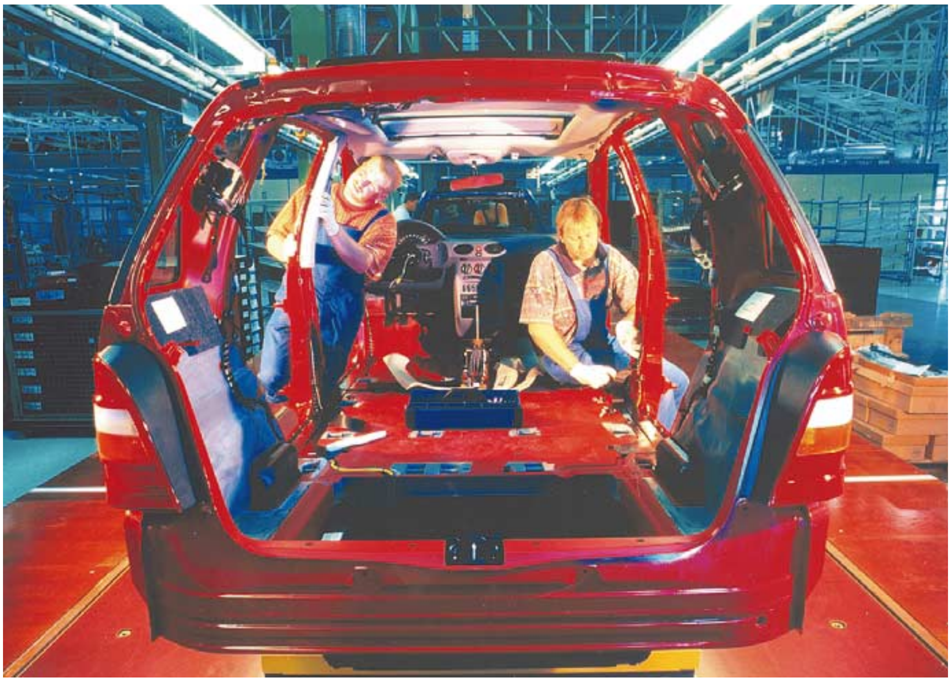

Figure 3. Owing to customers' requirements, completion of the interior of the car requires more workers than robots, that is, this stage is more labour intensive than the remainder of the car.

not needed. The final layer is a clear lacquer that is free of polluting solvents (**Figure 2**).

Once the robots have carried out their allotted tasks, the shell goes to the 'white room'. In this, human operators inspect the paint quality in a bright, completely white space. In this environment, no blemish escapes the inspectors – no robot is perfect!

Assembly

During assembly, the doors are attached to the shell, after which the car is completed to customers' requirements. The work is carried out by robots as well as people – in fact, it is the most labour-intensive stage of car manufacturing (**Figure 3**).

The assembly line contains a mixture of different models: right- or left-hand drive; automatic, semi-automatic or manual transmission; different sizes and types (petrol/diesel) of engine; and interior finishes. All more or less heavy labour is carried out by robots. For example, they fit the windscreen (US: windshield) with millimetre precision, build in the seats, and attach the bootlid (US: trunk lid).

Whereas parts are delivered 'just in time', the sub-systems are delivered 'just in sequence'. Fifty per cent of the parts required for assembly are delivered directly to the main assembly line. Five hundred or so workers fit the bulky, subject-to-model items, such as seats, door fittings, and cable harnesses. These items are fed on to the belt by a conveyor trolley.

Finally

And so, after 22 working hours, a new customized vehicle rolls off the assembly line. A box containing the data of all customer requirements is attached to the chassis so that these requirements can be read again during a final inspection and test.

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Excursus

Robots

The Robotic Industries Association defines an industrial robot as 'a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks'.

The name robot is taken from the Czech 'robota', meaning forced labour. Modern use of the word stems from Karel Capek's 1921 play Rossum's Universal Robots, in which mass-produced robots in human form turn on their creators and exterminate them.

Robots used by Daimler-Chrysler

The robots used in the German Daimler-Chrysler plant mentioned earlier are not typical of those used generally in the automobile industry, but they serve well as an example. They are KUKA Types IR360/125 and IR360/150. The final three digits indicate their maximum loading in kilograms. These robots do not need anti-torque weights since hydraulic mass equalization is provided. This facility also enables the robot to correct its movements if these deviate from the programmed patterns. Since these robots are accurately 'cloned', there is no problem in substituting one by another or in replacing parts.

Manufacturing

The first requisite in the manufacturing of cars is an accurately controlled flow of materials into the assembly plants. Many car manufacturers produce most of the required components and materials themselves. However, a number of components, for example, tyres, batteries and dashboard instruments are generally procured from outside sources.

Worldwide, most car manufacturers use the same kind of assembly process (although the Daimler-Chrysler plant mentioned earlier in the article uses a method whereby the body and frame are assembled as a unit).

Normally, there are two main assembly lines: body and chassis, on both of which robots are used extensively. On the first, the body panels are welded together, the doors and windows installed, and the body painted and trimmed (upholstery, interior hardware, wiring). On the second, springs, wheels, steering gear, power train (engine, transmission, drive shaft, differential), brakes and exhaust system are installed.

The two lines merge at the point at which the car is finished but for minor items and inspection and testing (by human operators).

Over the years, assembly lines have been refined by automatic control systems. In Britain, automatic transfer machines were introduced as early as 1950. The first large-scale automated installation was taken into use by the Ford Motor Company engine plant in Detroit, USA, in 1951.

Industrial robots

Virtually all industrial robots provide a substitute for human labour that is repetitive, hazardous or uncomfortable for the worker (spray painting, spot welding, arc welding, operations involving lasers), or where the task requires the handling of a part or tool that is heavy or awkward or both to handle. Moreover, the same robot can be used on consecutive shifts throughout a 24-hour period, seven days a week, 365 days a year, interrupted only for maintenance. To carry out these tasks, robots must be

- freely programmable
- servo controlled
- designed to have at least three axes
- equipped with grippers and tools
- designed for maintenance and processing tasks

In all cases, however, a robot is normally used only when this is economically sound. Since in the modern world, labour is getting more and more expensive (at roughly 5 per cent per year), and robots are getting less and less expensive (by roughly 5–8 per cent per year), more and more robots will be used in the world's manufacturing plants.

Types of teleoperator

Basically, there are several types of teleoperator (mechanical manipulator) used in robots, but all are made up of a series of links and joints. There are five basic types of joint to construct the manipulator: two are translational and three are rotational.
The teleoperator is usually divided into two parts: arm-and-body, and wrist. The various possible axes (degrees of freedom of movement) of a 6-joint manipulator are shown in **Figure 1**. Axes 1, 2, and 3, are the principal joints of the teleoperator that enable turning, stretching and bending, actions comparable to the arm sweep, shoulder swivel, and elbow movement of the human arm. Axes 4, 5, and 6, enable movements akin to those of the human wrist: yawing, pitching, and rolling.

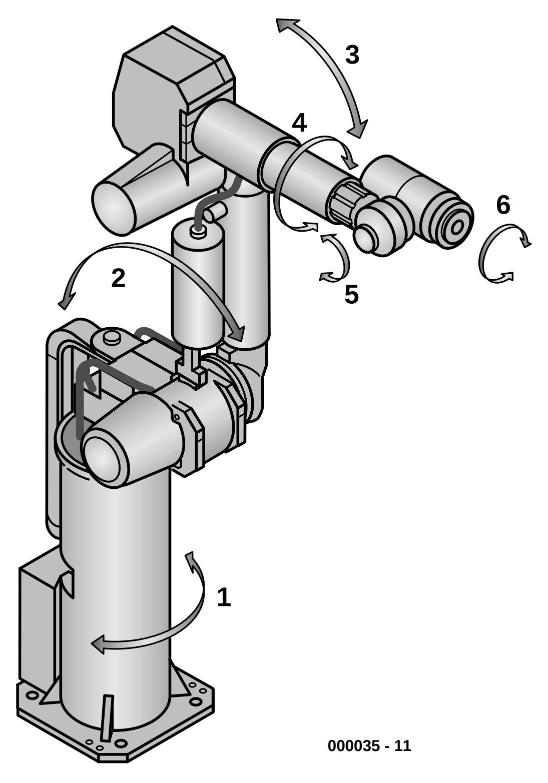

Figure 1. A robot with 6 axes (degrees of freedom).

The principal axes position the wrist joints in space. These joints can therefore orientate grippers or tools in space in such a way that processing or maintenance tasks can be fulfilled. When, for instance, a screw is being turned, joints 1–5 are used to bring the screwdriver, that is, joint 6, into the correct position. Compared with this manipulator, those with three or four joints are clearly less versatile, although they may well be perfectly all right for use with less demanding tasks.

Linear manipulators

Linear manipulators, also called Cartesian manipulators, usually have three principal joints (Figure 2). These enable up-and-down, side-to-side, and crossways movements. Often, there is a fourth joint that enables turning a tool around the z-axis.

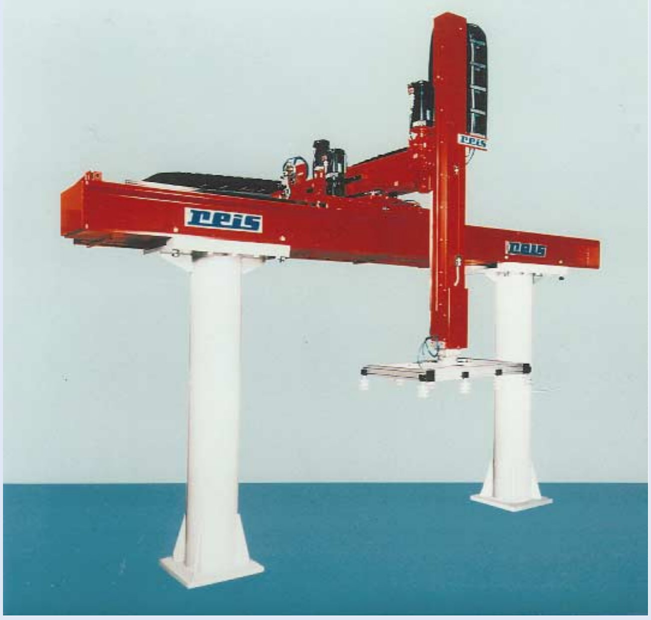

Figure 2. Linear teleoperator with three translational joints.

The work space, also called work envelope, of a linear teleoperator is cuboid. Modular adaptation of the possible travel of a single joint enables the envelope to be modified. Axis 1 (x-axis) enables longitudinal travel of up to more than 15 metres (50 ft). Owing to the maximum permissible mechanical load the travel of axes 2 and 3 (crossways and up-and-down respectively) is restricted to 2–3 metres (7–10 ft).

Roll manipulators

Roll or cylindrical manipulators normally have four degrees of freedom. These are provided by three rotational (or spin) joints that can revolve around the z-axis and one translational joint that operates along the z-axis. Often, however, only joints 1 and 2 are rotational and joint 3 translational. The fourth joint to turn the tool along the z-axis is then integrated into, or fitted to, joint 3. The work envelope of a roll teleoperator is cylindrical, or very nearly so.

Yaw manipulators

Yaw teleoperators are derived from swivel manipulators: three wrist joints are added to the three main joints (Figure 3). The added joints are arranged so that they can be yawed (that is, moved in the horizontal plane, whence the name of the manipulator).

The work envelope of this type of manipulator is cylindrical. Because of the differential arrangement of joints 1–3, the cross-

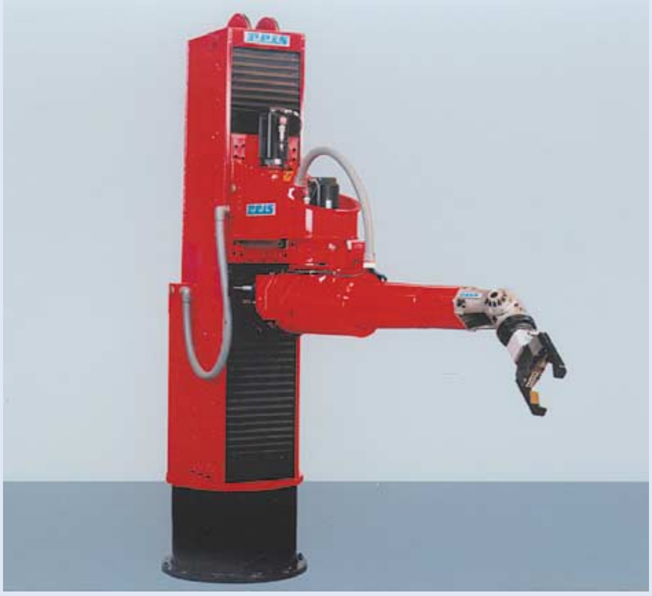

Figure 3. Yaw manipulator.

section of the cylinder may be circular or cardioid. The diameter of the work envelope depends on the length of the links connecting the rotational joints: currently, diameters of up to 5 m (16 ft) are possible.

Pitch manipulators

Pitch teleoperators are widely used in industrial applications (Figure 4). Three wrist joints are added to the rotational joints (one for vertical and two for horizontal movements). The wrist joints pitch (that is, move in a vertical plane, whence the name of this type of manipulator).

The work envelope of this type of manipulator is basically spherical. The extent of the envelope, particularly the inner space of the hollow sphere, is strongly dependent on the degree of freedom of the various joints. In the case of large robots, the diameter of the sphere may be as much as 5.5 m (18 ft).

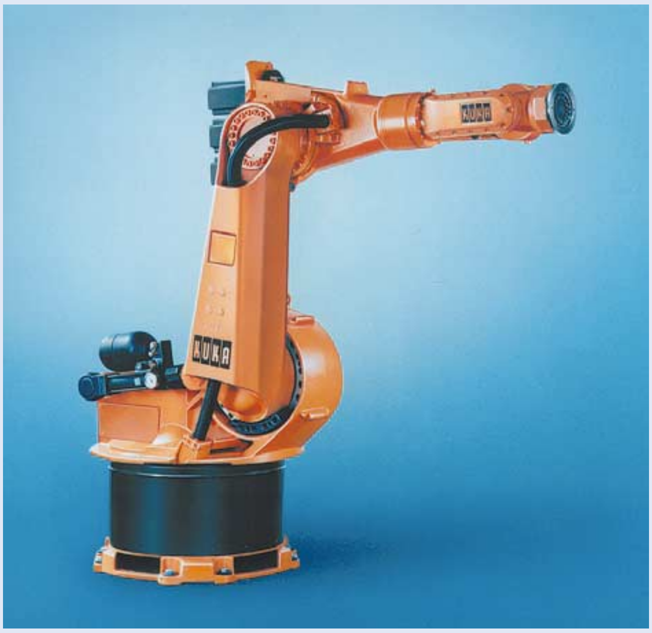

Figure 4. Pitch manipulator.

Special manipulators

Apart from the basic types of teleoperator discussed, there are many types of special manipulator, depending entirely on the application. Some provide improved access, others more rigidity, and yet others more freedom of movement.

Operation and programming

Some industrial robots are operated and programmed with the aid of a special control panel (Figure 5). This control panel allows all necessary instructions to be input and the operation of the manipulators to be actuated. The keypad of the panel is divided into clear functional sections separated by coloured lines. Integrated light-emitting diodes (LEDs) guide the operator to the many input facilities. Pull-down menus and groups of user and application specific softkeys enable fast programming in a straightforward manner.

Another programming tool is a 6-D mouse. After this has been calibrated in accordance with the manipulator's co-ordinates, it enables the teleoperator to be moved in all six directions of freedom to the desired position.

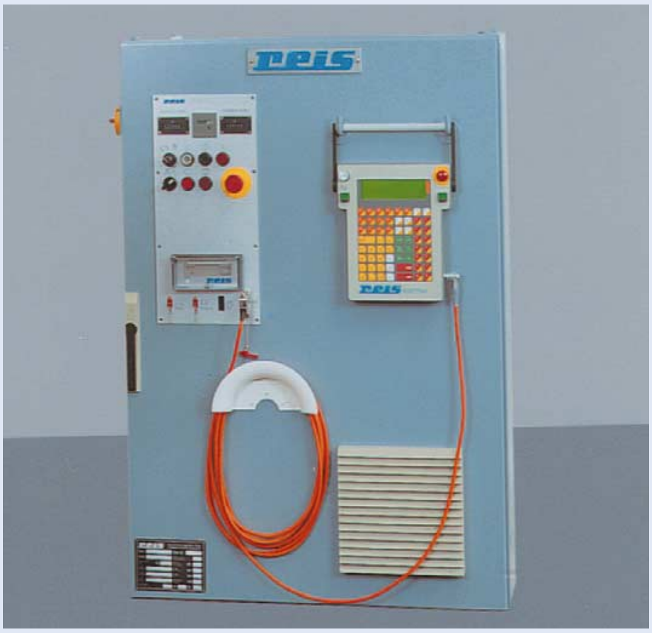

Figure 5. Control unit and operating panel in enclosure.

To prevent accidental operation of industrial robots (which are powerful and fast), the actual movement of the manipulators is enabled only after the 'safe' (or 'consent') key on the control panel has been pressed. The switch operated by this key controls security functions after the robot has been set up. When the relevant switch section is open, the manipulator can move at speeds of more than 25 cm/s only when the 'safe' key is held depressed. When the operator releases the key or presses it to the end position (out of fear?), the robot control is switched off. During direct programming, the robot cannot be active.

Normally, however, industrial robots are programmed by special computers. The software in these computers can, of course, easily be replaced or modified for the manufacture of different products. The programming language is usually APT (Automatically Programmed Tools), but there is increasing use of Flexible Manufacturing Systems (FMS), which coordinate design, production control, and manufacturing in a site-wide computer network linked with LANs, such as Ethernet, MAP and Fieldbus.

Computer programming is followed on a VDU, which requires good spatial perception. Even when all co-ordination points have seemingly been programmed correctly, some may have to be trimmed or corrected in a teach-in operation. Even programming with CAD/CAM software is invariably followed with such an operation.

Hardware

The numerical control unit of the robot consists of several electronic cards linked by a bus system. The central unit is the main processor that determines the overall co-ordinates of the robot control. Superimposed on this unit are joint-regulating processors that carry out the positioning and monitoring of the various joints. The performance of the main processor in current robot control units is comparable to that of, say, a Motorola Type 68040 or Intel 486.

The matching unit provides communication between the robot and peripheral equipment, for instance:

- interface to robot (reading and writing the data as to position of manipulators; driving the servo control; operating the brakes);
- binary interface to peripheral elements (control of grippers and conveyors; reading/writing of sensor data);
- analogue interface to processes (control of processes; reading/writing of analogue sensor data);
- interface to auxiliary processors (off-line programming system; master processor; PPS processor; CAD processor).

Communication often takes place over a 3-wire CAN (Controller Area Network) bus, because of the high transfer security and minimum cable requirements of this bus. (See Elektor Electronics Sept–Dec 1999).

The power unit provides supply voltages for the various electrical and electronic units.

Servos control the joints of the manipulator(s) in line with instructions from the robot control. Their use ensures that the movement of the teleoperators is arranged with great precision. The requisite three-phase motors are driven in such a manner that, depending on the amplitude of the current and the current/voltage phase relationship, the rotary moment is in precise accordance with the instructions from the robot control unit.

The protection unit is an important unit not only for the robot system, but also for the operator. It provides traditional voltage and temperature monitoring, an emergency stop switch for the hardware and software, and input diagnosis of all switch actions. The unit also monitors switching systems like the ‘safe’ switch and emergency stop switch, and the speeds during setting-up operations.